THE CARBON DID IT - MASKING SURFACE ICE FEATURES ON SMALL DISTANT BODIES. G. Sarid[1,2] , R. Brunetto[3,4] , F. E. DeMeo[5] and M. Kueppers[4], [1]Earth and Planetary Sciences, Harvard University, 20 Oxford Street, Cambridge, MA 02138, USA. [2]NASA Astrobiology Institue, University of Hawai'i, 2680 Woodlawn Drive, Honolulu, HI 96822, USA, galsarid@fas.harvard.edu. [3]Institut d'Astrophysique Spatiale, CNRS, UMR-8617, Universite Paris-Sud, batiment 121, F-91405 Orsay Cedex, France. [4]European Space Astronomy Centre (ESAC), European Space Agency, Apartado de Correos 78, 28691 Villanueva de la Canada, Madrid, Spain. [5]Earth, Atmospheric, and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, MA 02139, USA.

Introduction: Surface compositions of small bodies in the outer Solar System are derived mostly through analysis of measurements in the visible and near-infrared (NIR), with estimates of albedo, photometric colors and diagnostic spectral features [1]. Centaurs and trans-Neptunian objects exhibit low surface albedos. Some of the widest color variation of any other Solar System population, ranging from neutral gray to the reddest colors and lack distinguishing absorption features apart from some hints of water ice, for all but the largest objects [2, 3].

Small bodies in the outer Solar System are believed to be rich in ices, hydrocarbons, complex organics, and more refractory carbon-rich materials, such as amorphous carbon [4]. A mixture of these materials, together with other rock compounds, should be responsible for the spectral colors of small icy bodies. Complex organic materials on such surfaces likely include a primary native component that accreted during planetesimal formation epoch, and a secondary component that is a by-product of ion and photon irradiation of simpler C-bearing volatile compounds.

Additional insight into the surface composition of small icy bodies comes from the laboratory study of cometary grains, such as some interplanetary dust particles (IDP) collected in the Earth's stratosphere [5, 6], or grains collected from comet 81P/Wild 2 by the *Stardust* spacecraft [7]. These studies indicate the presence of refractory carbonaceous units that are usually sub-micron in size. This indicates that the size of every sub-unit is much smaller than the wavelengths commonly covered in surface spectroscopy. Based on this evidence, it has been suggested that reddening of small icy bodies may be caused by sub-micron particles from organic material of pre-solar or protoplanetary origin trapped in ice [8].

To extend these results, We have developed a spectral model for small icy bodies that is compatible with volatile loss and surface processing by solar and cosmic ions. This model is based on results derived from laboratory measurements of collected cometary grains and IDPs [9].

Model: Following the approach presented in [8], we use Maxwell-Garnett effective medium theory to approximate the effect of sub-wavelength refractory inclusions. This procedure takes the optical constants of several components and mixes them according to their respective mass fractions and densities. If all inclusions are considered spherical and the dielectric properties of the medium and inclusions are similar, we can compute the average wavelength-depnedent dielectric function. Next, we employ the Hapke model to calculate multiple scattering by the aggregate particles and produce disk-integrated albedo spectra.

We focus on the nature of the refractory dust and examine a broad range of compositions, in particular including silicate and iron sulfide components and a more realistic representation for the carbon component. While it is true that a-priori we do not know the composition of refractory components in the outer Solar System, we can certainly assume the cometary dust composition as the best currently known analog for small outer Solar System bodies and a good starting point to explore the visible-NIR spectral effects of the different mixtures (silicates vs. carbons, etc.). The materials we consider in our model are: Crystalline and amorphous silicates (olivine and pyroxene), iron sulfides, and a large variety of carbonaceous materials. We assume the composition of a well-characterized cometary IDP as a sort of ``reference dust'' [9], from which we let vary the different relative abundances.

We choose three key parameters that we calculate from the synthetic spectra, which are used to characterize outer Solar System bodies [10, 11]: Depth of the 2 micron water ice band, R-band albedo (as well as V-band) and a color index (B-V and V-R).

Results: We refer here to our derived results as a scheme for the effects of sub-micron inclusions on the reflectance spectra. Thus, we do not try to perform any rigorous fitting or analysis of the whole available volume of spectral observations of icy surfaces.

Fig. 1 shows a mapping of the 2 micron fractional band depth onto the ice-carbon mass fraction space. These fractions cover the range from pure-refractory to pure-ice grains (x-axis, 0 to 1) and from carbon-depleted to completely carbonaceous refractory inclusions (y-axis, 0 to 1). These results are for the small-scale grains and low-sensitivity observations. We have also calculated the same for larger grains (20 and 50 microns) and for high-sensitivity observations. Even small inclusions of carbon, in terms of mass fraction, are extremely efficient at masking the icy composition of a grain, at both the small and large size limits.

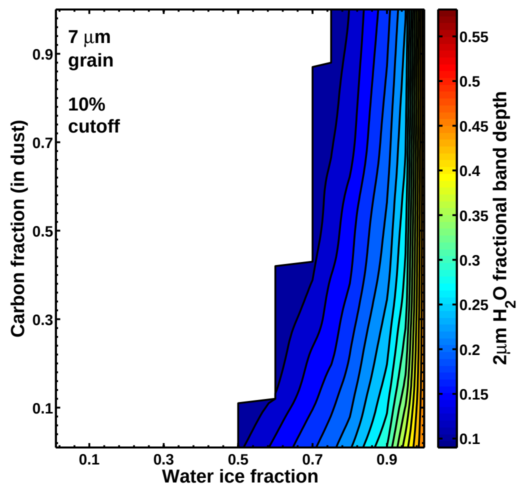

Figure 1: Fractional band depth of the 2 micron band for different proportions of water ice and carbon fractions in the dust.

Fig. 2 presents our calculated R-band albedo for the large and small grain sizes, as a function of water ice mass fraction in the grain. We can see that the sub-resolution mixing of water-ice and refractory components renders the albedo independent of composition and grain size, up to ~0.35 water ice mass fraction. At the mass fraction range where the curves differ, only small grains with dust components moderately-enriched in carbon have albedo values similar to the estimates relevant for icy objects in the outer Solar System [10].

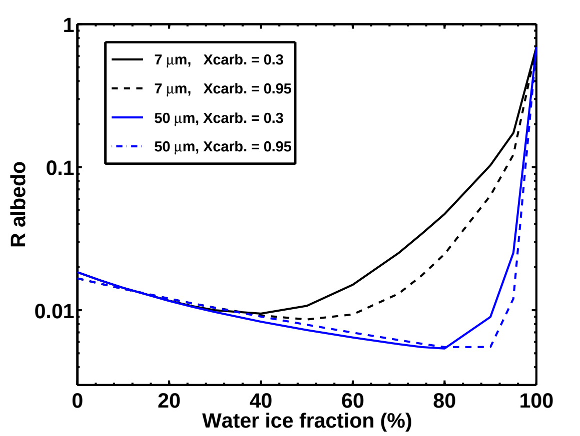

Figure 2: R albedo variation, as a function of water ice fraction in the grains, for "average" and enriched carbon fraction inclusions in the dust.

Our models show that a lack in detectable water ice band depth does not necessarily mean a lack of considerable fraction of water ice, if it is mixed in the grain-aggregate level. We find that over 50% (by mass) of water ice can be spectroscopically masked at 10% detection sensitivity due to the strong absorption of the carbonaceous sub-inclusion component. This effect is roughly similar to the one found for carbon-enriched crusts [12]. Comparing with ion irradiation experiments [13], we find that sublimation induced volatile loss and destruction of volatiles due to space weathering display a very similar spectral trend (flat-bright/red/flat-dark).

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